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Fuzzy logic Controlled Three Phase PWM Rectifier

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***Abstract*—this paper presents the use of the hysteresis current controller and the fuzzy logic theory to control a three phase pulse width modulation three phase rectifiers (PWM rectifier). This technique is used to eliminate harmonics currents and consequently to reduce total harmonic distortion (THD) of the line current and improve the power factor. The fuzzy logic controller is applied to maintain the DC capacitor voltage at the required level, while the line of currents drawn from the power supply should be sinusoidal and in phase with respective phase voltages to satisfy the unity power factor operation of the PWM rectifier. The study made in this paper compares the three phase full diode rectifier and PWM rectifier. It analyses the performance of these systems for power quality improvement. Simulation results are presented and commented.**

Keywords*— *PWM* rectifier; Fuzzy logic; hysteresis band current, line current, compensation, power factor, correction.

I. INTRODUCTION

The non-linear loads equipments such as fluorescent lamps switching, power supplies electric, furnace high-voltage, DC systems adjustable speed drives and AC/DC conventional converters produce harmonics. The harmonic and reactive power cause poor power factor and distort the supply voltage source and network [1-4]. However, the use of the nonlinear loads such as AC/DC conventional rectifiers such as diode rectifier bridge has become a serious problem, , the input current of this rectifier contains a large number of harmonics, which has become to the main source of grid and consequently low power factor [1-4]. To solve this problem in the power systems, a number of solutions have been developed and put into practice. The use of the active power filters and PWM rectifiers are two typical examples of these solutions. The active power filter and PWM rectifier have basically the same circuit configuration and can operate based on the same control principle.

The PWM rectifier has six power transistors with anti-parallel diodes. These diodes are mainly used to carry out the PWM generation as well as the power bidirectional conversion. The converter is supplied by three-phase source in series with coupling inductance (L_c), and is the inductance between the grid and the PWM rectifier [4, 7]. This converter have some important advantages: does not produce harmonic distortion in line current, bi-directional power flow, regulation the power factor to unity, adjustment and stabilization of DC-link voltage and reduced the size of DC filter capacitor [8]. In particular, several standards have introduced important and stringent limits on harmonics that can be injected into the power supply [9, 10]. In recent years different strategies have been proposed for controlling PWM converter.

In this paper, hysteresis band current based based on fuzzy logic controller is proposed to control the three-phase PWM rectifier. The performances of the converter are evaluated using Matlab/Simulink. Fig.1 shows the basic circuit topology of the PWM rectifier :

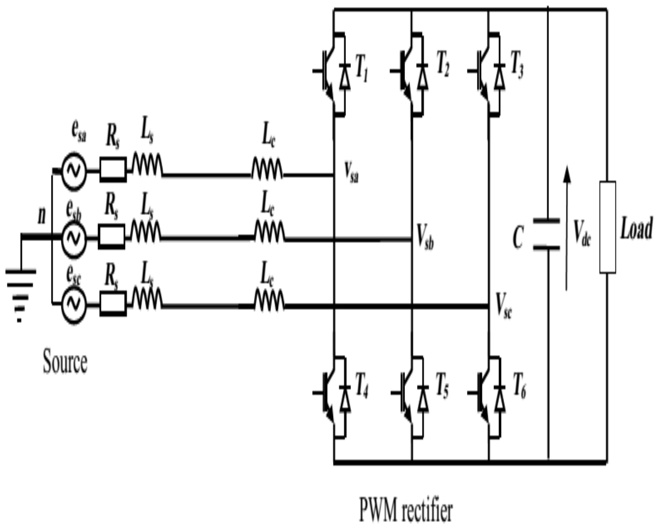

Fig. 1. Three-phase PWM rectifier converter

II. ANALYTICAL MODEL OF THREE-PHASE PWM RECTIFIERS

Three phase voltage source fed PWM rectifier and the lines current are given by (1) and (2), respectively [11]:

$$\begin{cases} e_a(t) = E_{\max}\ \sin(\omega t) \\ e_b(t) = E_{\max}\ \sin(\omega t - \dfrac{2\pi}{3}) \\ e_c(t) = E_{\max}\ \sin(\omega t - \dfrac{4\pi}{3}) \end{cases} \quad (1)$$

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$$\begin{cases} i_a(t) = I_{\max} \sin(\omega t + \varphi) \\ i_b(t) = I_{\max} \sin(\omega t - \frac{2\pi}{3} + \varphi) \\ i_c(t) = I_{\max} \sin(\omega t - \frac{4\pi}{3} + \varphi) \end{cases} \quad (2)$$

Where, E_{max}, I_{max}, $w=2.pi.f$ and φ are, respectively, amplitude of the phase voltage, maximum current, angular frequency, and angular phase.

With assumption:

$$i_a(t) + i_b(t) + i_c(t) = 0 \quad (3)$$

In α, β stationary system, the equations (1) can be expressed by:

$$\begin{cases} e_{s\alpha}(t) = \frac{\sqrt{3}}{2} E_{\max} \sin(\omega t) \\ e_{s\beta}(t) = \frac{\sqrt{3}}{2} E_{\max} \cos(\omega t) \end{cases} \quad (4)$$

Similarly, the input voltages in the synchronous d-q coordinates are expressed by:

$$\begin{cases} e_{sd}(t) = \frac{\sqrt{3}}{2} E_{\max} = \sqrt{e^2{}_{sd} + e^2{}_{sq}} \\ e_{sq}(t) = 0 \end{cases} \quad (5)$$

Line to line input voltages of PWM rectifier can be described as:

$$\begin{cases} u_{ab} = (S_a - S_b) * V_{dc} \\ u_{bc} = (S_b - S_a) * V_{dc} \\ u_{ca} = (S_c - S_a) * V_{dc} \end{cases} \quad (6)$$

And phase voltages are equal:

$$\begin{cases} v_a = f_a * V_{dc} \\ v_b = f_b * V_{dc} \\ v_c = f_c * V_{dc} \end{cases} \quad (7)$$

Where the switching states of the PWM rectifier are:

$$\begin{cases} f_a = \frac{2S_a - (S_b + S_c)}{3} \\ f_b = \frac{2S_b - (S_a + S_c)}{3} \\ f_c = \frac{2S_c - (S_a + S_b)}{3} \end{cases} \quad (8)$$

The f_a, f_b and f_c are assume 0 , ± 1/3 and ± 2/3.

The voltage equations for balanced three-phase system without the neutral connection can be written as [6, 7]:

$$\begin{cases} e_a = v_a + Ri_a + L\frac{di_a}{dt} \\ e_b = v_b + Ri_b + L\frac{di_b}{dt} \\ e_c = v_c + Ri_c + L\frac{di_c}{dt} \end{cases} \quad (9)$$

And, additionally for currents is:

$$C\frac{dv_{dc}}{dt} = S_a i_a + S_b i_b + S_c i_c - i_{dc} \quad (10)$$

A block diagram of PWM rectifier corresponding to equations (10 and 11) is shown in Fig. 2.

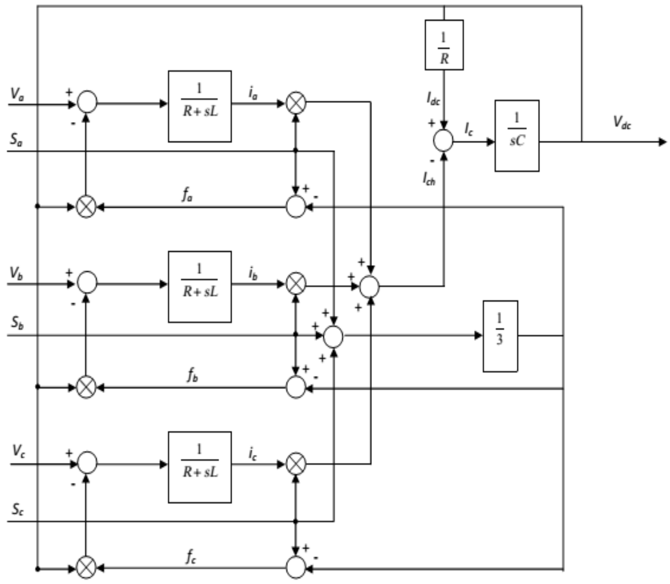

Fig. 2. Block diagram of voltage source PWM rectifier

III. CONTROL OF PWM RECTIFIER

In order to improve the line current sinusoidal waveform, with power factor equal to unity, hysteresis band current based on fuzzy logic controller is proposed, this technique is used to generate directly the switching states for the PWM rectifier when the error between the reference and the actual value exceeds an assigned tolerance band [8-10]. Fig. 3. Show the basic circuit topology of proposed system. The three phase current references are generated using the PLL system taken from three phase AC source and by multiplying them by the output signal current of the DC voltage controller [12-15].

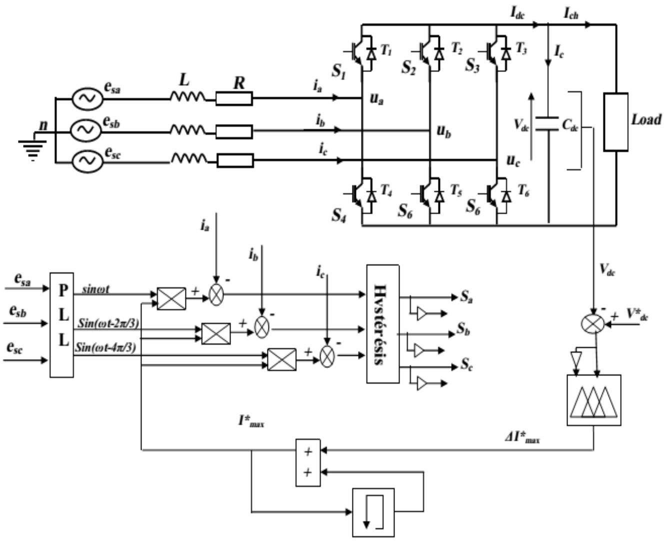

Fig. 3. Hysteresis control current of PWM

A fuzzy logic controller (FLC) is applied to maintain the constant voltage across the capacitor by minimizing the error between the capacitor voltage (V_{dc}) and the reference voltage (V^*_{dc}). To design the FLC, variables which can represent the dynamic performance of the system to be controlled should be chosen as the inputs to the controller. The error (*e*) and the rate of error (*de*) are taken as controller inputs and the maximum amplitude current (*Imax*) requirement for voltage regulation is taken as the output of the FLC, shown in Fig. 4.

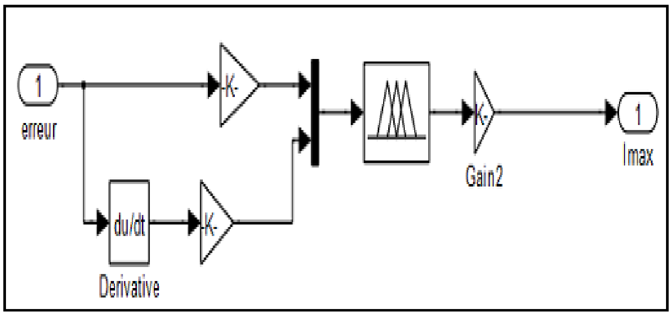

Fig.4. Schematic diagram of fuzzy controller

The input and output variables are represented respectively by five and three linguistic variables , namely, NB (Negative Big), NS (Negative Small), Z (Zero), PS (Positive Small), PB (Positive B) and N(Negative), Z (Zero), P (Positive). Fuzzy the Rule Base variables for DC voltage control are shown in table.1.

e(k) / $\Delta e(k)$	NB	NS	Z	PS	PB
N	PB	PS	PS	Z	NB
Z	PB	PS	Z	NS	NB
P	PB	Z	NS	NS	NB

Table 1 Fuzzy Rule Base for DC voltage control

IV. SIMULATION RESULTS

To show the effectiveness of strategies control of PWM rectifier, numerical simulation of the proposed system was carried out by using MAtlab/Simulink, the line to line input voltage source take the value of 50sqrt(3) V, the initial value of the DC link voltage V_{dc} is regulated at 140V. To validate the effectiveness of the control strategy studied in this paper, all spectrum analysis harmonic figures are under the levels imposed by international standards recommendation IEEE 519-1992, in terms of total distortion harmonic (THD). The load value is R =45Ω.

It can be seen in Fig.5 and Fig.6, the input voltage and the line currents of the three phase full diode rectifier distorted due to the presence of harmonics, in this case, the spectrum harmonics analysis, where the THD is 29.29%, that is far the limit of the harmonic standard, shown as Fig.7.

PWM rectifier, presents a clear improvement in the line currents waveforms. In the Fig. 8 the line input currents are sinusoidal and the spectrum harmonics analysis shown in Fig. 9, gives a THD of 2.87% that is within the limit of the harmonic standard [9-10].

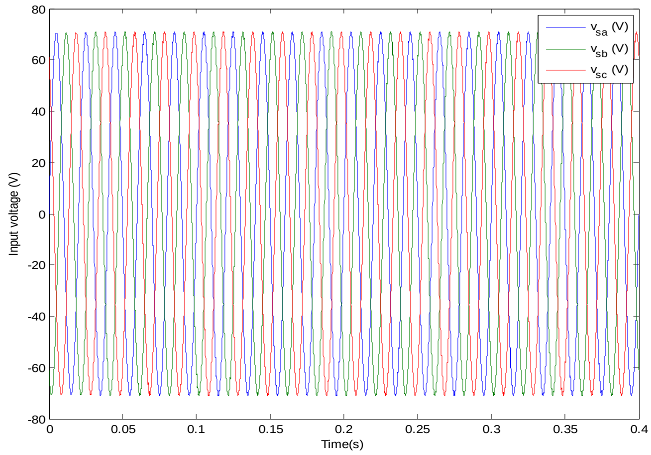

Fig.5 The input voltage of PWM rectifier

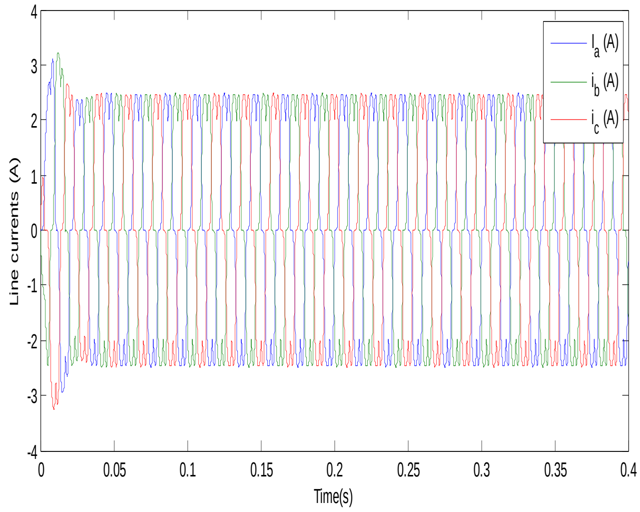

Fig.6 Line currents of full diode rectifier

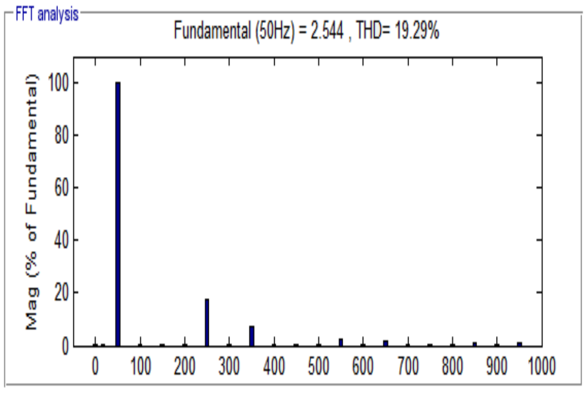

Fig.7 Spectrum harmonic of line current of full diode rectifier

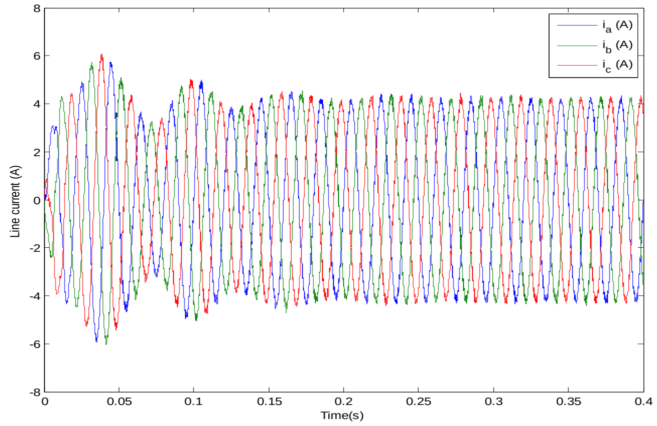

Fig.8 Line currents of PWM rectifier

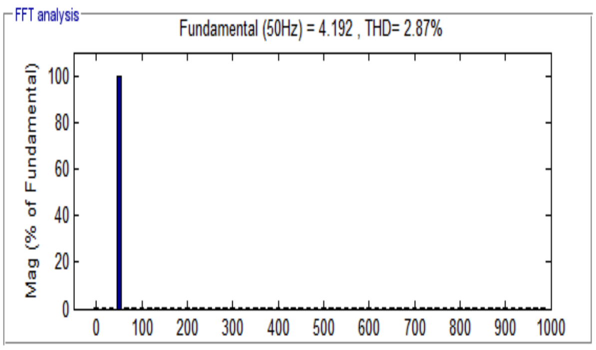

Fig.9 Spectrum harmonic of line current of PWM rectifier

Fig.10 shows the line current and the input voltage. In the presence of PWM rectifier, It can be seen that the line current is sinusoidal and nearly in-shape with the respective phase voltages.

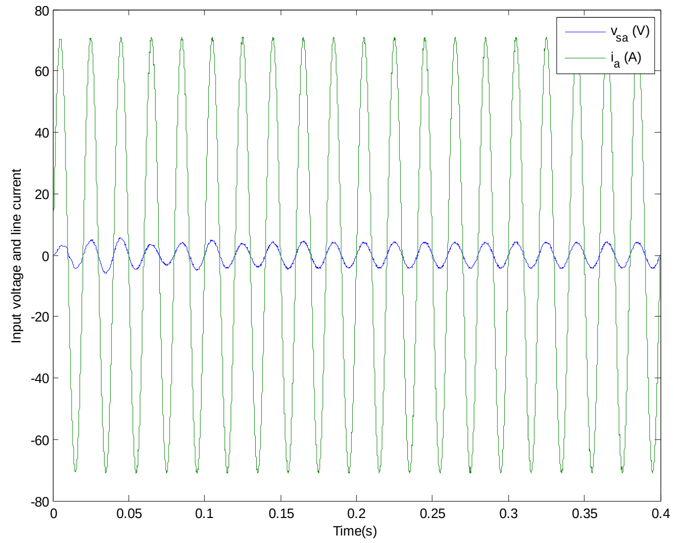

Fig.10 Input voltage and line current superposition of PWM rectifier

In order to implement the control algorithm of a PWM rectifier, the DC capacitor voltage (V_{dc}) is sensed and compared with the reference value (V_{dc} reference). Fig.11 shows the DC capacitor voltage variation with and without FLC controller, can be seen that his value follows up its initial reference value fixed at 140V only with presence of FLC controller. In order to test the robustness an effectiveness of PI controller, the reference value have been changed to 160V at t= 0.4s, the capacitor voltage source keeps tracking his reference with good dynamic performance.

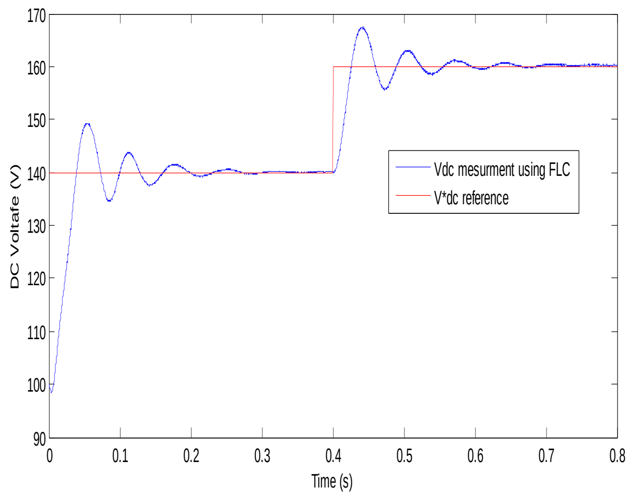

Fig.11 DC capacitor voltage regulation bloc of PWM rectifier

The instantaneous three-phase active and reactive powers and power factor are presented respectively in Fig.12 and 13. It can be clearly shown that the reactive power flow is zero consumption, which is very favorable for the system performances and so the power-factor is almost equal to unity.

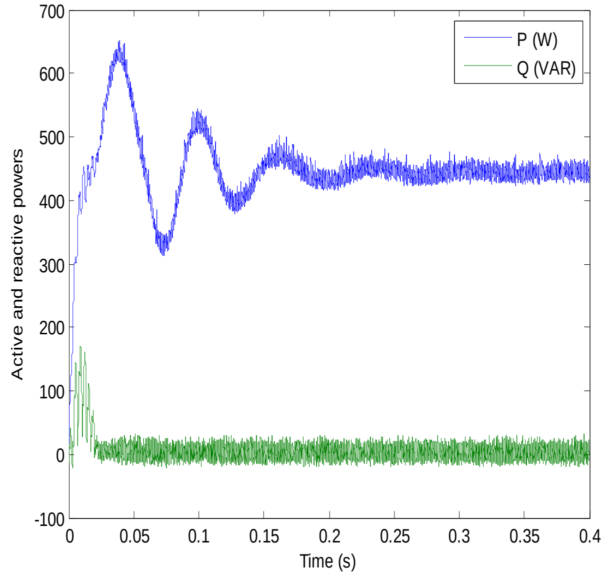

Fig.12 Active and reactive powers of PWM rectifier

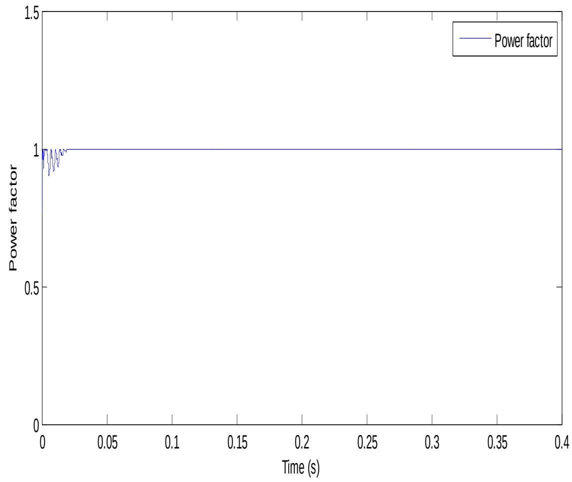

Fig.13 Power factor of PWM rectifier

V. CONCLUSION

In this paper, the performance of the PWM rectifier is analyzed using hysteresis current controller technique and the fuzzy logic theory for minimizing harmonics and compensating reactive power in the power system. The simulation results presented in this paper confirm that the fuzzy logic controller improves the system performances. These improvements affect the performances of the system response on the power-factor correction and the THD of the line sinusoidal current. The use of this advanced technique has an extremely simple and robust structure and excellent dynamic performance.

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